1,083,574

PATENT SPECIFICATION

DRAWINGS ATTACHED

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Int. Cl.:—F 24 f // F 05 h, F 25 b, G 05 d

COMPLETE SPECIFICATION

Cabin Air Conditioning Apparatus for Aircraft

We, BRISTOL SIDDELEY ENGINES LIMITED, a Company registered under the Laws of Great Britain, of Stonebridge House, Colston Avenue, Bristol 1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to aircraft cabin air conditioning apparatus of the kind including means for delivering fresh air to a cabin under pressure from two independent sources, each having associated with it flow control apparatus, e.g. from the air compressors of two propulsion engines or pairs of propulsion engines of the combustion turbine type, and has for its object to provide certain improvements in such air conditioning systems which, amongst other advantages, will tend to enable and/or ensure that satisfactory air conditioning is maintained irrespective of the number of sources of air supply, e.g. engine compressors, which are in effective operation, that failures such as failures of electric equipment, the supply of servo fluid or similar failures will not produce unsafe or unsatisfactory cabin air conditions, and that as far as possible the system will continue to operate satisfactorily in spite of failures other than very improbable failures, while the risk of human error in an emergency causing or increasing the risk of dangerous cabin conditions being experienced, due for example to failure to diagnose or take immediate action on the occurrence of some failure, is reduced.

For convenience the term "cabin" is used herein to mean the whole or any part of the total pressurised cabin space of an aircraft, except where some specific part of such total space is referred to specifically.

Aircraft cabin air conditioning apparatus according to the present invention includes means for delivering fresh air to a cabin under pressure from at least two sources each of which has associated with it flow control apparatus, for controlling the volumetric rate of flow of such fresh air, each flow control apparatus having two settings corresponding respectively to a higher and to a lower flow rate, and control means arranged to set the flow control apparatus associated with each of the two sources at the higher flow rate setting if and when the rate of flow from the other source drops below a predetermined value.

The control means associated with each source preferably includes in addition automatic means, responsive to the difference between ambient atmospheric pressure and cabin pressure, arranged to set the flow control apparatus at the higher flow rate setting when said difference drops below a predetermined value and to maintain the flow control apparatus at the lower flow rate setting when said difference is above a predetermined value. In addition there may be provided manually operable means by which the automatic means can be over-ridden in emergency.

By selecting an appropriate pressure difference for the automatic operation of such control means therefore, it will be seen that it is possible to ensure that, if the desired cabin pressure is not maintained at any altitude above a predetermined altitude, the flow control apparatus is automatically moved to its high flow rate setting and thus provides for the high flow rate from the fresh air source in question irrespective of the cause of the cabin pressure having dropped below that desired.

The flow control apparatus of each source may conveniently be arranged to be actuated by apparatus which is responsive to the delivery pressure of the other source and arranged so that the flow control apparatus of each source is set or maintained at its higher flow rate setting if air under pressure from the other source is not available, the normal

setting or maintenance of each control apparatus at its higher flow rate setting when air under pressure from the other source is available being effected by isolating the flow control apparatus of the appropriate source from the delivery pressure of the other source. Thus, the flow control apparatus of each source is conveniently biassed towards its higher flow rate setting and urged into its lower flow rate setting by air-operated servo apparatus the operating air for which is derived through a control passage from the air delivery passage of the other source, while there is a shut-off valve in each control passage arranged to be closed when the difference between cabin pressure and atmospheric pressure drops below the predetermined value referred to. If at any time, therefore, air under pressure from either source becomes unavailable, the flow control apparatus of the other source is automatically set or maintained at its higher flow rate setting.

The invention is particularly but not exclusively applicable to cabin air conditioning apparatus embodying two similar sets of air conditioning apparatus in accordance with the invention forming the subject of the present applicants' co-pending Patent Applications No. 9793 (Serial No. 1083573) of 1963 and No. 24625 of 1963, that is to say apparatus in which each set is arranged to receive fresh air from the compressors of one or more propulsion engines of the combustion turbine type and includes heat discharge apparatus through which such air flows comprising a compressor-turbine unit in which the air is compressed by the compressor, flows through one or more heat exchangers for the extraction of heat therefrom, and is then expanded in the turbine so as to constitute the working fluid thereof before being delivered to the cabin, and air recirculating apparatus including a recirculating compressor arranged to draw air (herein called recirculated air) from the cabin and deliver it back to the cabin through heat exchange apparatus in which heat is extracted from it, the recirculating compressor being driven for example by a turbine actuated by air derived from the cabin and discharged to the atmosphere after passing through the turbine.

The control apparatus for such a turbine-compressor recirculating unit according to a further feature of the present invention may include by-pass means by which air can be circulated through the compressor and by-pass means in a closed circuit under conditions in which the turbine provides insufficient power to enable the compressor to operate with a compression ratio sufficient to cause recirculation.

Moreover where the turbine of the recirculating turbine-compressor unit in such an arrangement is arranged to be driven by "vitiated air" from the cabin prior to discharge of such air to atmosphere, further by-pass means may be provided permitting said "vitiated air" and further "partially vitiated" air to by-pass the turbine compressor unit and flow to atmosphere under conditions in which the difference between cabin pressure and ambient atmospheric pressure is inadequate to enable sufficient power to be derived from the turbine for recirculation of said partially vitiated air to be maintained by the recirculating compressor.

One example of cabin air conditioning system according to the invention and certain details thereof are shown somewhat diagrammatically in the accompanying drawings in which:

Figure 1 is a diagram of the cabin air conditioning system as a whole,

Figure 2 is a diagrammatic sectional side elevation and shows a form of valve device which may be embodied, in the manner hereinafter described, in the apparatus shown in Figure 1, and

Figure 3 shows a modification which may be applied to the valve apparatus shown in Figure 2.

In the arrangement shown in Figure 1 of the drawings referred to, the pressurised cabin accommodation with which the system is associated is indicated by the reference numeral 1 and the complete system comprises two similar sets of air conditioning apparatus each of which comprises a source of fresh air, means for cooling the fresh air, means for withdrawing air (herein for convenience called partially vitiated or recirculated air) continuously from the cabin, cooling such partially vitiated air and returning it, mixed with the cooled fresh air, to the cabin, and means for discharging continuously from the cabin to the atmosphere further air (herein for convenience called more fully vitiated air). While the partially vitiated or recirculated air and the more fully vitiated air may respectively be drawn from any convenient parts of the cabin accommodation, it will be understood that the more fully vitiated air would normally be drawn from parts of the cabin accommodation such as that constituting the galley, the lavatory accommodation and/or the luggage compartment, while the recirculated air would be drawn from and returned to the part of the cabin accommodation to be occupied by passengers and/or personnel. In each "set" of air conditioning apparatus the source of fresh air is constituted by the compressor of one or each of a pair of propulsion engines 2 of the combustion turbine type which to this end are arranged to deliver air through passages 3 containing non-return valves 3*a* and heat exchangers 3*b* to a common fresh air supply passage 4, the heat exchangers employing as their cooling fluid "ram air" that is to say air derived from one or more forwardly facing air intakes on the aircraft and discharged again to atmosphere after passing through the heat exchangers. The two passages 3 of each pair of engines communicate

with one another through a passage 3*c*, while the two passages 4 are capable of being brought into communication with one another, but are normally isolated from one another, by a valve 4*a*.

In each set the fresh air supply passage 4 is arranged to deliver air through a pressure reducing valve 5 and a flow control device 6, having high and low flow rate settings, to the inlet of the air compressor 7 of a turbine-compressor unit 8 of the boot-strap type, from the outlet of which compressor the air flows through a heat exchanger 9 employing ram air as the cooling fluid, and a second heat exchanger 10 (hereinafter further referred to), to the nozzle ring 11 of the turbine 12 of the turbine-compressor unit 8. The outlet from the turbine 12 leads through a passage 13 to a point 14 where this passage is joined by a passage 15 for air from a recirculating unit as hereinafter described, after which the fresh air, mixed with such recirculated air, flows through a mixed air delivery passage 16 to the cabin 1.

In each set of air conditioning apparatus the recirculating apparatus comprises a turbo-compressor recirculating unit 17 of the rotor of which has a ring of turbine blades 19 (hereinafter referred to for convenience as the turbine) carrying a ring of compressor blades 18 (hereinafter referred to for convenience as the compressor). The turbine 19 is arranged to be actuated by air (herein referred to as the more fully vitiated air) derived through a passage 20 from the cabin 1, which air after passing through the turbine 19 flows via a heat exchanger 21, a passage 22 and the heat exchanger 10, to a valve and nozzle assembly indicated at 23 the function of which is hereinafter described. The more fully vitiated air flowing through the passage 22, the temperature of which has been reduced by passage through the turbine 19, thus constitutes the cooling fluid in the heat exchanger 10.

The compressor 18 is arranged to draw air (herein referred to as the partially vitiated air) through a passage 24 from the cabin 1 and to deliver it via the heat exchanger 21 and the passage 15 to the point 14 where, as above described, it mixed with fresh air from the fresh air supply system and flows back to the cabin 1 through the passage 16.

A shut-off valve 25 and a three-way valve 26 are provided in the passage 20 with a similar shut-off valve 27 and three way valve 28 are provided in the passage 24, the three-way valves 26 and 28 being arranged so that under appropriate conditions they can shut off flow or more fully vitiated air and partially vitiated air respectively to the turbine 19 and compressor 18 and cause such air to flow through restrictors 29 and 30 and a by-pass passage 31 direct to the passage 22.

The valves 26 and 28 and the flow control device 6 of each set are biassed by spring pressure and/or cabin pressure towards the settings in which respectively flow through the restrictors 29 and 30 is permitted and the fresh air flow at the higher flow rate is maintained, and are arranged to be urged to their other settings by air pressure derived through a passage 32, containing a shut-off valve 33, from a point 34 in the fresh air turbine inlet passage of the other set when this pressure exceeds cabin pressure by an amount sufficient to ensure operation of the fresh air boot-strap unit 8. The valves 25 and 27 are similarly arranged to be opened by pressure derived via a passage 35 and the appropriate passage 32, from the fresh air turbine inlet passage of their own set.

A by-pass passage 36 is provided between the inlet passage 24 of the recirculating compressor 18 and the delivery passage 15, this by-pass passage being controlled by a valve device indicated at 37 in which the valve is operated by a servo device receiving its working fluid in the form of compressed air through a passage 38 from the point 34 in the fresh air turbine inlet passage of its own set.

In addition there is a by-pass passage 39 extending between the point 14 and the inlet of the fresh air compressor 7 to enable the boot-strap system embodying the fresh air compressor-turbine unit 8 to be by-passed partially or wholly under certain conditions, this by-pass passage 39 being controlled by two valves 40, 41 arranged in series therein. The valve 40 is arranged to be controlled, for example electrically, through a control line indicated at 42 by a thermostatic device 43 in the passage 16 the setting of which is under the control of a thermostat 44 in the cabin. The thermostatic device 43 is also arranged to control, through a control line 45 and in a manner hereinafter described, the nozzle assembly 11 of the fresh air turbine, which is thus provided with adjustable inlet guide vanes. The valve 41 is a thermostatic valve (actuated other than electrically) subject to the temperature in the passage 16 as indicated by the dotted line 46.

For all temperatures in the passage 16 below a maximum value the valve 41 will be open while for temperature in the passage 16 below a predetermined lower value, determined by the setting of thermostat 44 the valve 40 will be fully open and the arrangement is such that with rises in the temperature in the passage 16 above the predetermined lower value, the thermostatic device 43 first progressively closes the valve 40 so as to increase the effectiveness of the boot-strap cooling system embodying the fresh air turbine compressor units, and then, with further rises in temperature after the valve 40 has been fully closed adjusts the adjustable nozzle assembly 11 of the fresh air turbine, to increase the pressure drop, and

hence the temperature drop, through this turbine while the flow control device 6 operates to increase the pressure at the entry to the compressor 7 so as to maintain the desired flow through the fresh air boot-strap system.

If, due for example to failure of the temperature control apparatus 43, 44 described above or to other causes the valve 40 does not close, so that the air temperature in the passage 16 rises above the predetermined maximum referred to, that is to say to a value liable to cause an undesirably high or dangerous temperature in the cabin, the thermostatic valve 41 closes so as to maintain the fresh air boot-strap cooling system in effective operation irrespective of the setting of the valve 40.

A relief valve 47 may be provided in the delivery passage of the compressor 7 to limit the maximum pressure which can be maintained in this passage to a safe value.

A continuous discharge valve 48 is provided by which a proportion of air is continuously discharged to atmosphere from the cabin, e.g. into the under-carriage bay of the aircraft, so as to maintain the desired pressure in the cabin.

The valve and nozzle assembly 23 is arranged and controlled so as to maintain in the passage 22 a substantially constant pressure below the lowest working cabin pressure, under all conditions when ambient atmospheric pressure is below that constant pressure. The pressure thus maintained by the valve and nozzle assembly 23 has a value such in relation to the pressure maintained in the cabin 1 as to provide a pressure drop across the turbine 19 at which this turbine will drive the compressor 18 at the rate necessary to maintain the pressure required at the point 14 to maintain effective circulation of air through the recirculating system. Thus for all altitudes above that at which the ambient atmospheric pressure is at the predetermined value mentioned the rate of recirculation is automatically maintained substantially constant.

The valves 33 are controlled by control apparatus (not shown) of a kind known per se, so as to be closed automatically by means responsive to the difference between ambient atmospheric pressure and the cabin pressure so that the valves 33 will be closed automatically under low altitude conditions when the difference between the cabin pressure and ambient atmospheric pressure is insufficient to drive the turbines 19 effectively, the control apparatus including a manual control by which the automatic control can be over-ridden in emergency.

When so closed each valve 33 shuts off the operating air supply to the three-way valves 26 and 28 and to the flow control device 6 of the opposite set so as to maintain the flow control device 6 at its high flow setting and to maintain the valves 26 and 28 in their "by-pass" position that is to say, the position in which the more fully vitiated and the partially vitiated air flows from the passages 20 and 24 through the by-pass passage 31. The restrictors 29 and 30 are proportioned to provide the correct relationship between the flow of more fully and partially vitiated air from the cabin and the flow of fresh air to the cabin with the pressure in the passage 22 maintained by the valve and nozzle device 23 at the predetermined value referred to above. Assuming now that the aircraft climbs, at an appropriate altitude (say about 22,000 feet) the valves 33 open with the result that the flow control device 6 will be moved to its lower flow setting and the flow of partially vitiated and more fully vitiated air to the recirculating turbine-compressor unit 17 will be permitted. The recirculating turbine-compressor unit thus begins to operate but, until the compressor 18 generates sufficient pressure, the by-pass passage 36 is maintained open by the valve device 37 so that the partially vitiated air is merely circulated from the compressor, through the heat exchanger 21 back to the inlet of the compressor. As soon as sufficient pressure is generated by the compressor 18 the valve device 37 operates to open the passage 15 and close the by-pass passage 36 and thus bring the recirculating turbine compressor unit 17 into effective operation.

The valve device 37 is in effect a servo-operated non-return valve employing a pilot valve operated by pressure difference, the operating air from the servo being derived from the fresh air turbine inlet passage of the same set as indicated by the pressure line 38 and one form which this valve device may take is shown diagrammatically in Figure 2 of the accompanying drawings while Figure 3 shows a modification.

In the construction shown in Figure 2, in which figure compressor 18 is shown diagrammatically, the arrangement comprises a by-pass passage 48 extending between the inlet and delivery passages of the compressor 18 and containing two restrictions 49, 50 between which is situated a pilot valve 51 the degree of opening of which thus determines the pressure in the chamber 52 on its upstream side. This chamber 52 communicates through a passage 52A with a chamber 53 on one side of a pressure-responsive diaphragm 54 the chamber 55 on the other side of which is subject through a passage 55A to the pressure in the passage 15. The diaphragm 54 is connected to a servo valve 56 with which is connected also suitable pressure balancing diaphragms 57 and 58, interposed respectively between the chamber 53 and a chamber 59 and the chamber 55 and a chamber 60, the chambers 59 and 60 being interconnected so that the valve 56 is unaffected by forces other than those due to the pressure difference between the chambers 53 and 55. The two

chambers 59 and 60 are connected to the fresh air turbine inlet by the passage 38, and the valve 56 is arranged to control the flow of air from the chamber 59 through a passage 61 to the working chamber 62 of a piston type servo device, the flow out of which chamber 62 takes place through a restricted vent 63 while the piston 64 of the servo device is acted upon by a compression spring 65. Thus the position of the piston 64 is determined by the relationship between the cross-sectional area of the vent 63 and the effective cross-sectional area allowed at any moment by the valve 56 for air flow from the chamber 59 to the chamber 62. The servo piston 64 is connected by a linkage 67*a* to a main valve 66, shown as a butterfly valve, in the passage 15 on the downstream side of the point at which the by-pass passage 48 is connected thereto and also by a linkage 67*b* to the valve 51.

Thus, the valve 66 is maintained closed as long as the pressure in the passage 15 is above that in the chamber 52, which under these conditions is between delivery pressure of the compressor 18 and the pressure in the passage 24.

When, however the delivery pressure of the compressor 18 rises to a point where the pressure in the chambers 52 and 53 exceeds that in the passage 15 and chamber 55, the valve 56 begins to open and thus cause movement of the piston 64 to open the valve 66 and close the valve 51. The initial movement in this sense by closing the valve 51 causes a further increase in the pressure in the chambers 52 and 53 so that at the appropriate compressor delivery pressure the valve 66 is opened with a rapid movement. Once the valve 51 is closed, the pressure in the chamber 52 will be the compressor delivery pressure and if this drops below the pressure in the passage 15, the valve 66 will close.

Figure 3 shows an alternative form of servo valve 67 which may replace that shown at 56 in Figure 2, the valve 67 being of the piston type actuated by a diaphragm 68 subject to differential pressure in the same way as the diaphragm 54, the valve 67 being formed in a manner known per se so that with movement in one direction from a neutral position it connects the passage 38 communicating with the fresh air turbine inlet, to a relief passage 69 while with movement in the opposite direction from the neutral position it connects the passage 38 to the passage 61 leading to the working chamber of the servo device.

It will be apparent that since the flow control device 6 of each set of air conditioning apparatus is spring-biassed towards its high flow setting and is normally maintained at its low flow setting by air pressure derived through the appropriate passage 32 from the point 34 in the fresh air turbine inlet passage of the other set so long as this pressure exceeds cabin pressure by an amount sufficient to ensure operation of the fresh air boot-strap unit 8, if a fault occurs in the boot-strap unit 8 or in its associated control valves of either set causing the pressure at the point 34 to fall below the required pressure, the flow control device of the other set will automatically move to its high flow setting and the valves 25 and 27 of the failed set will close, stopping recirculation and air discharge through that set. Moreover since the valves 26 and 28 of each set are also actuated by air from the fresh air turbine inlet of the other set, these valves of the properly operating set will, on such failure, automatically be moved into the position in which the recirculating turbine compressor unit 17 is by-passed. This is necessary to keep the cabin temperature down to the desired value, the temperature of the recirculation air leaving the heat exchanger 21, when the recirculating unit 17 is in operation, being higher than the desired cabin temperature, and the cooling capacity of the boot-strap unit 8 being insufficient in the high flow case to compensate for this.

It should be noted that failure of the air supply source associated with one air conditioning set, i.e. one pair of engines 2, will temporarily cause the flow control valve 6 of the other air conditioning set to be adjusted to the high flow condition, and recirculation by both sets to be stopped, but that by opening the valve 4*a* both sets can be brought back into normal operation.

It will be understood that air conditioning apparatus according to the invention may include means for filtering and/or deodorizing and/or controlling the humidity of air delivered to the cabin, for example by passing the recirculated air through filtering, and/or deodorizing and/or humidity control apparatus before it is mixed with fresh air and flows back to the cabin.

WHAT WE CLAIM IS:—

1. Aircraft cabin air conditioning apparatus including means for delivering fresh air to a cabin under pressure from at least two sources each of which has associated with it flow control apparatus for controlling the volumetric rate of flow of such fresh air, each flow control apparatus having two settings corresponding respectively to a higher and to a lower flow rate, and control means arranged to set the flow control apparatus associated with each of the two sources at the higher flow rate setting if and when the rate of flow from the other source drops below a predetermined value.

2. Aircraft cabin air conditioning apparatus as claimed in Claim 1, in which the control means associated with each source includes means responsive to the difference between ambient atmospheric pressure and cabin pressure, such means being arranged to set the

flow control apparatus at the higher flow rate setting when said difference drops below a predetermined value.

3. Aircraft cabin air conditioning apparatus as claimed in Claim 1 or Claim 2 in which the flow control apparatus associated with each source is biassed towards its higher flow rate setting and is arranged to be urged into its lower flow rate setting by air-operated servo apparatus the operating air from which is derived through a control passage from the air delivery passage of said other source, whereby said control apparatus is maintained at its lower flow rate setting by air pressure derived from said other source, against the action of the biassing means when said air pressure is above a predetermined value.

4. Aircraft cabin air conditioning apparatus as claimed in Claim 2 and Claim 3 wherein the control means controlling the setting of the flow control apparatus comprises a shut off valve arranged to interrupt the supply of air through the control passage when the difference between cabin pressure and ambient atmospheric pressure drops below the predetermined value.

5. Aircraft cabin air conditioning apparatus as claimed in any one of the preceding claims, including recirculating apparatus comprising a recirculating turbine-compressor unit including a turbine which is arranged to be driven by air derived from the cabin on its way to discharge to the atmosphere and including control apparatus for such turbine-compressor recirculating unit including by-pass means by which air can be circulated through the compressor of the unit and the by-pass means in a closed circuit under conditions in which the turbine provides insufficient power to enable the compressor to operate with a compression ratio sufficient to cause recirculation.

6. Aircraft cabin air conditioning apparatus as claimed in Claim 5 in which the turbine of the recirculating unit is arranged to be driven by "vitiated air" from the cabin prior to its discharge to atmosphere, and including further by-pass means permitting said "vitiated air" and further "partially vitiated" air from the cabin to by-pass the turbine-compressor unit and flow to atmosphere under conditions in which the difference between cabin pressure and ambient atmospheric pressure is inadequate to enable sufficient power to be derived from the turbine for recirculation of said partially vitiated air to be maintained by the recirculating compressor.

7. Aircraft cabin air conditioning apparatus as claimed in any one of the preceding claims, in which the flow path by which air flows from each of the two sources to the cabin includes a compressor-turbine unit of the bootstrap type comprising a compressor, a heat exchanger and a turbine through which the air passes in succession and including by-pass means by which part of the air can be caused to by-pass the compressor-turbine unit and/or the heat exchanger, and means responsive to the temperature of the air being delivered to or in the cabin for controlling said by-pass means.

8. Aircraft cabin air conditioning apparatus as claimed in Claim 1 or Claim 2 or Claim 3 including recirculating apparatus comprising a recirculating turbine-compressor unit including a turbine which is arranged to be driven by air derived from the cabin on its way to discharge to the atmosphere and valve means arranged to control such discharge to the atmosphere and to maintain a substantially constant pressure in the discharge passage below the lowest working cabin pressure under all conditions when ambient atmospheric pressure is below that constant pressure, whereby the power developed by the turbine of the recirculating unit driven by air passing through said discharge passage tends to be maintained constant for all ambient atmospheric pressures below said constant pressure.

9. Aircraft cabin air conditioning apparatus substantially as described with reference to Figure 1 of the accompanying drawings with or without the specific form of valve device described with reference to Figure 2 or with the modification described with reference to Figure 3.

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Agents for the Applicants.

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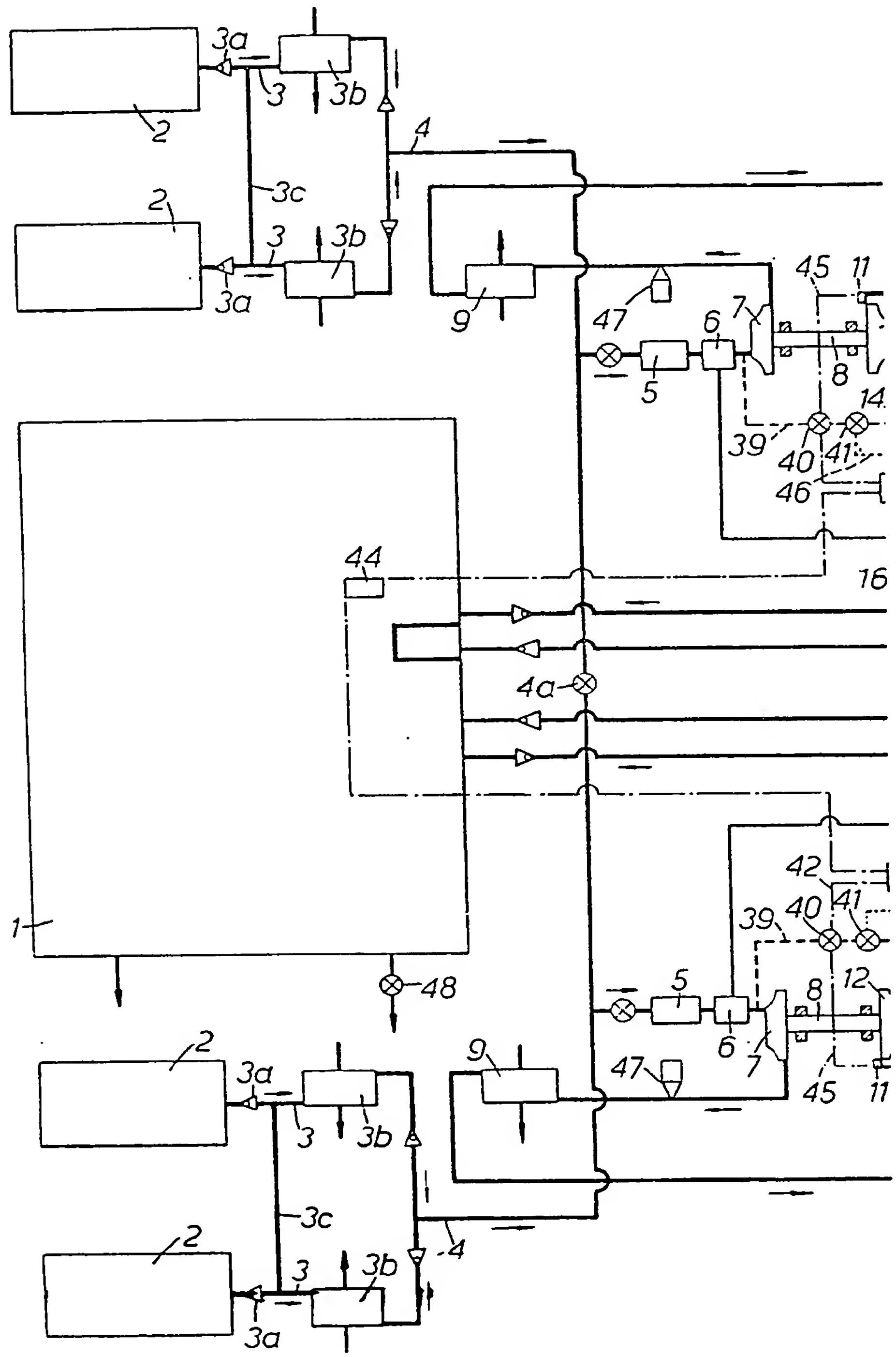
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1083574 COMPLETE SPECIFICATION

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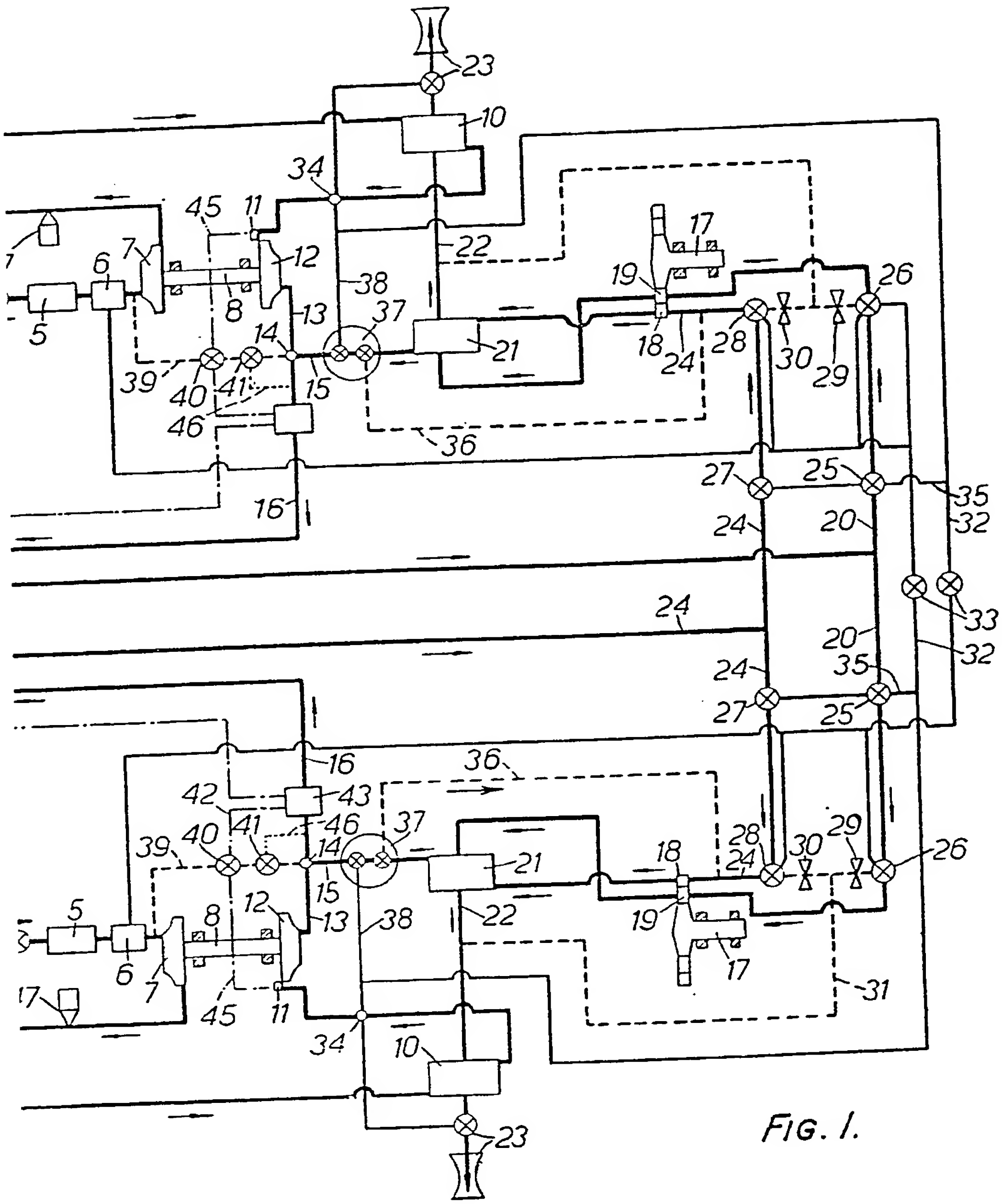

FIG. 1.

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Sheet 1

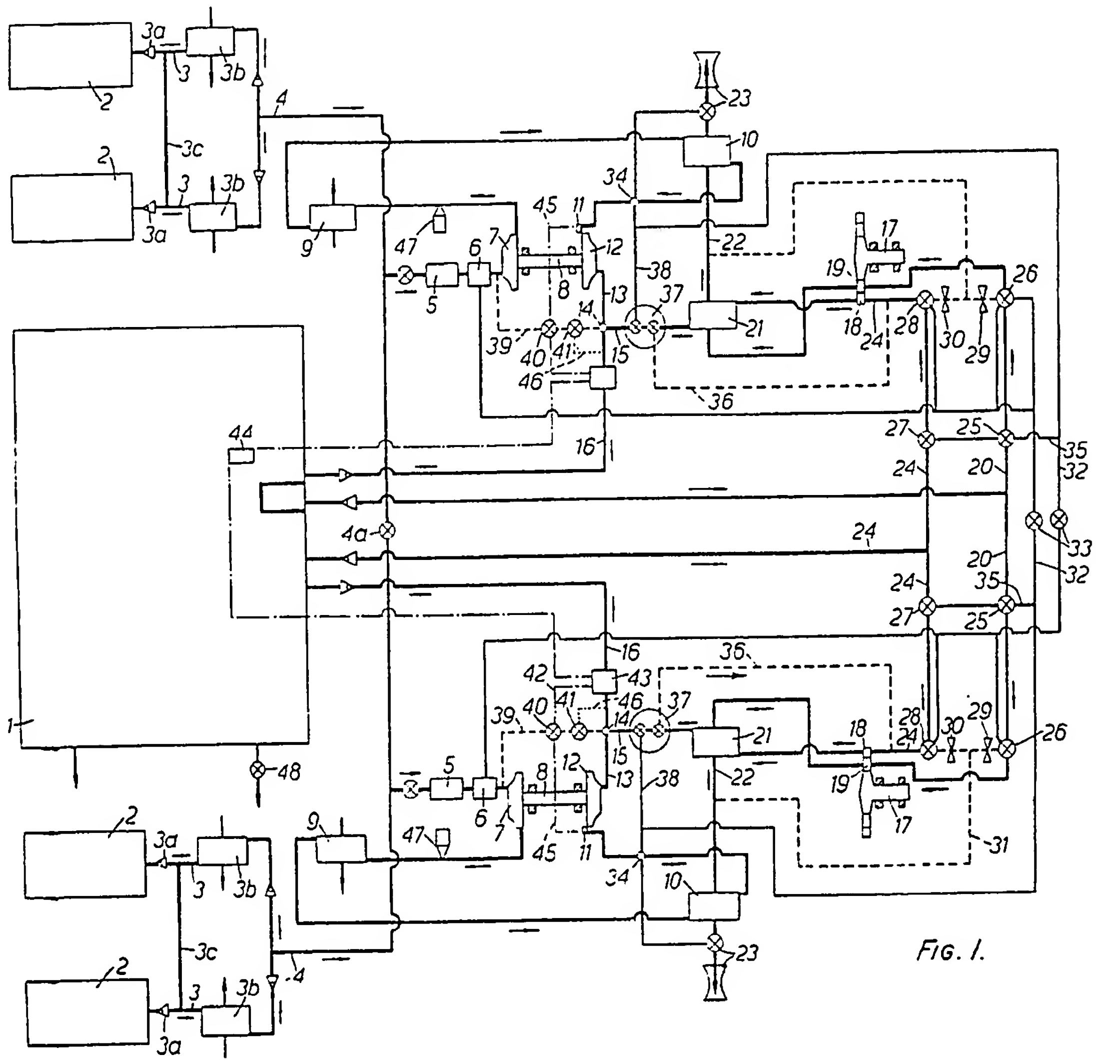

FIG. 1.

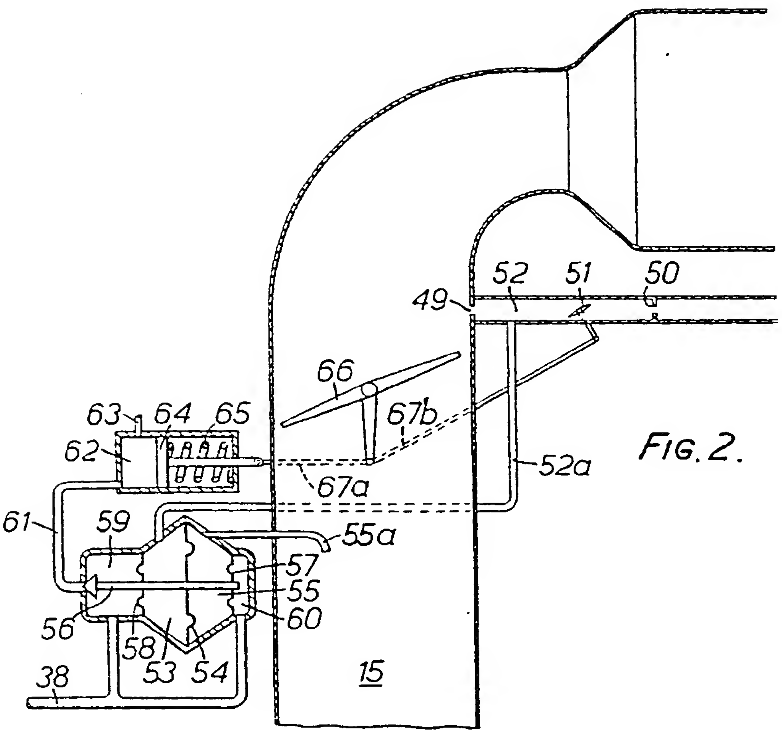
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FIG. 2.

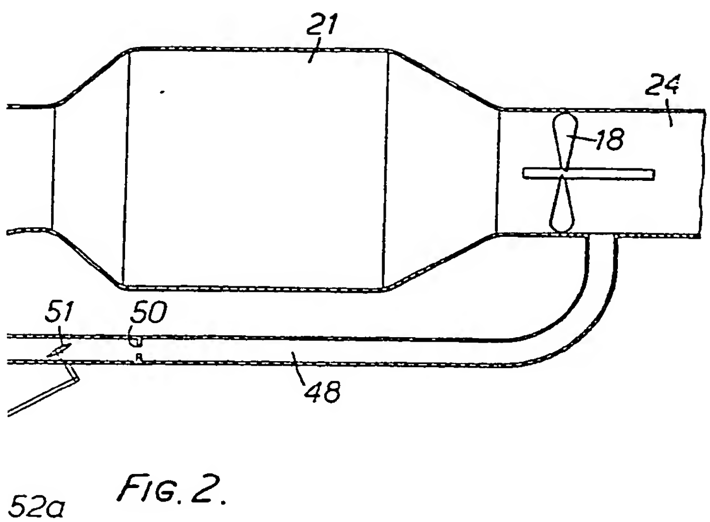

FIG. 2.

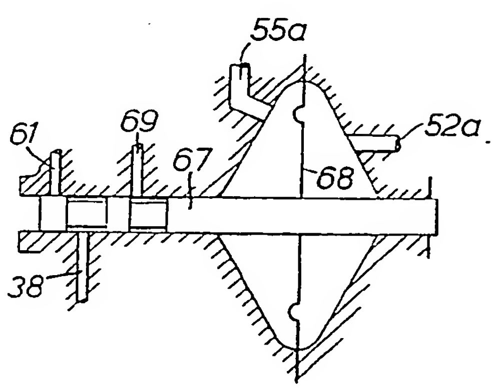

FIG. 3.

1083574 COMPLETE SPECIFICATION
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Sheet 2

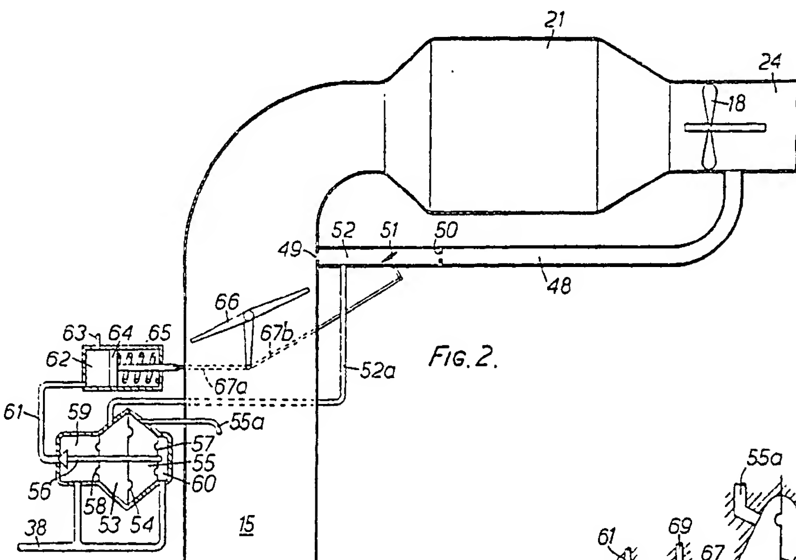

Fig. 2.

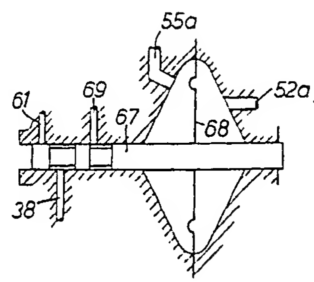

Fig. 3.